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AFATL-TR-70-51

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**PENETRATION OF 60-GRAIN  
AND 240-GRAIN BOMB  
FRAGMENTS INTO WALLBOARD**

TECHNICAL REPORT AFATL-TR-70-51

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**AIR FORCE ARMAMENT LABORATORY**

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PENETRATION OF 60-GRAIN AND 240-GRAIN  
BOMB FRAGMENTS INTO WALLBOARD

Richard P. Warnis

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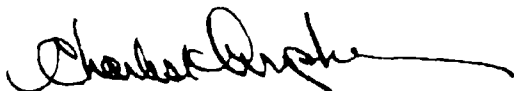
## FOREWORD

Presently, the Degradation Effects Program (DEP) and others are using regression equations relating the striking velocity for cylinders as a function of their penetration into wallboard. This effort grew out of the question of whether actual bomb fragments would have a similar regression equation. This final phase of the study, which is concerned with testing 60-grain and 240-grain bomb fragments, was conducted during the period 1 January - 1 March 1970. The results from firing 15-grain bomb fragments into wallboard are available in AFATL-TR 70-18.

The DLRD range crew composed of Jack Byrne, TSgt Charles Sauls, Clyde Wallace, Sgt Ron Stearns, Sgt Terrell Costello, Sgt Dennis Houtari, Sgt Earl Farabaugh, and Sgt William Carson provided the necessary technical support and instrumentation.

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This technical report has been reviewed and is approved.



CHARLES K. ARPKE, Lt Col, USAF  
Chief, Technology Division

# ABSTRACT

The primary objective of this program was to define a function between the striking velocity for 60-grain and 240-grain random shaped bomb fragments and their depth into the wallboard trade named Nu-Wood. The 60-grain fragments were fired from a 20mm Mann barrel and the 240-grain fragments from a 30mm Mann barrel into bundled Nu-Wood. The 60-grain fragments were lightly filed to fit into a  $3.77 \leq w \leq 4.01$  gram weight range and the 240-grain fragments into a  $15.08 \leq w \leq 16.02$  gram weight range. The striking velocities for the 60-grain fragments were in the 600 ft/sec to 5000 ft/sec range and the 240-grain fragments in the 300 ft/sec to 3500 ft/sec range. The graph of fragment striking velocity as a function of depth into Nu-Wood showed a wide range of depths for approximately 2000 ft/sec and above striking velocities. A lower dispersion in penetration depths exists for velocities up to 2000 ft/sec. A least squares curve would not be valuable since the penetration spread is too wide at given velocities. Fragment penetration into Nu-Wood from firing cylinders does not give a realistic picture of 60-grain and 240-grain actual bomb fragmentation spread. The depth of penetration is not a primary function of the initial presented areas of impacting 240-grain fragments for 500 ft/sec to 3000 ft/sec velocities. When a factor of two or more exists between impacting presented areas for 60-grain bomb fragments, then the presented area seems to influence penetration.

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## SECTION I

### INTRODUCTION

Actual 60-grain and 240-grain bomb fragment firings into Nu-Wood were conducted at Range 22, Eglin AFB, during the months of January through March 1970.

The primary objective was to define a function between striking velocity and depth into Nu-Wood. Secondary objectives were:

- a. To find if the penetration into Nu-Wood is a function of the presented area of the impacting fragment.
- b. To observe the breakup characteristics of 60-grain and 240-grain bomb fragments in Nu-Wood.
- c. To determine the extent of deflection of the fragments relative to projected paths in air and Nu-Wood.

## SECTION II

### TEST SET-UP

The general test set-up for the firings is shown in Figure 1. Figure 2 shows the co-ordinates  $X_1Y_1$ ,  $X_2Y_2$ , and  $X_3Y_3$  on the three-dimensional view of the Nu-Wood. The lower left hand corner of the Nu-Wood serves as the origin.



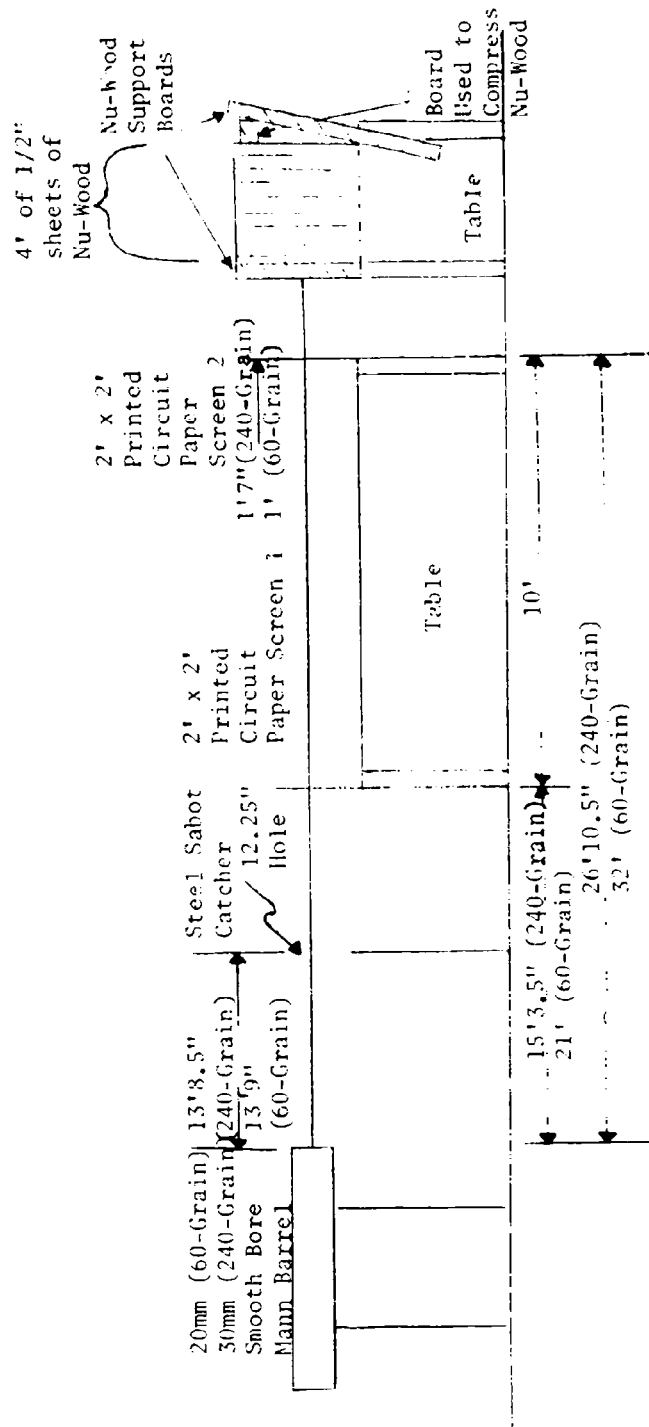


Figure 1. Test Set-Up

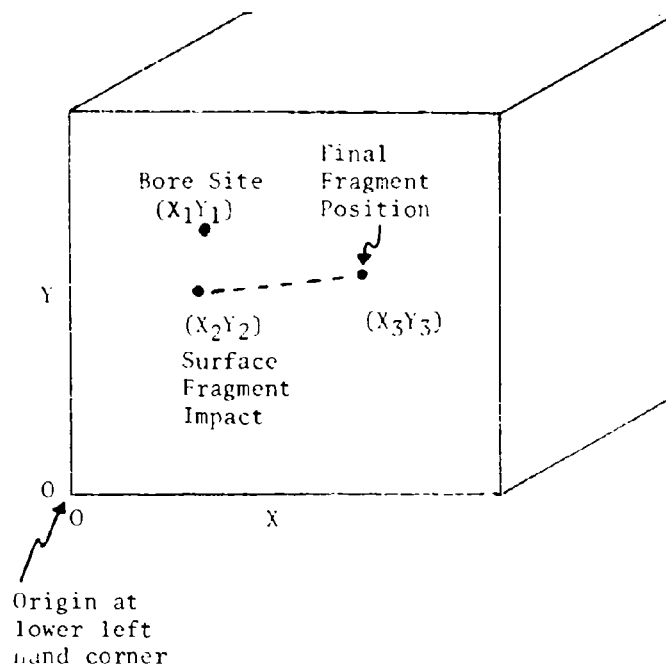


Figure 2. X and Y Co-ordinates on the Nu-wood

### SECTION III

#### PRIMARY OBJECTIVE

Figures 3 and 4 show the striking velocity as a function of penetration for 60-grain and 240-grain fragments. These striking velocities were obtained by correcting the fragment measured velocity for air drag. The air drag correction times the measured velocity was 0.9514 for 60-grain fragments and 0.9661 for 240-grain fragments. These were obtained from: <sup>1</sup>

$$V_S = \bar{V} \left[ \frac{\frac{-\alpha(S-x)}{m^{1/3}} - \frac{-\alpha S}{m^{1/3}}}{\frac{\alpha x}{m^{1/3}}} \right]$$

$V_S$  = Striking velocity (feet/sec).

$\bar{V}$  = Average measured velocity between the screens. The first screen is at  $x_0=0$ , the second at  $x=10$  feet (ft/sec).

$S$  = Distance from the first screen to the target (11 feet for 60-grain fragments and 11.58 feet for 240-grain fragments).

$\alpha$  = 0.0327 (constant for an air drag coefficient  $C_d = 0.640$ , and density of air,  $\rho = 0.310$  grains/in<sup>3</sup>.)

$M$  = Mass of fragment in grains.

Valid data points and data points estimated from powder charges are plotted on Figure 3. The fragment weight range of 3.77  $\leq w \leq$  4.01 grams for 60-grain fragments and 15.08  $\leq w \leq$  16.02 grams for 240-grain fragments is not a function of depth into Nu-Wood. Figures 3 and 4 illustrate the wide spread in depths of penetration.

A means of classification of the fragments into shape categories was found from close examination of the fragments and solving for D in:

$$LWD = \frac{w}{\rho}$$

LWD = Length Width Depth where  $L > W > D$  (in.).

$w$  = Weight of fragment (lbs.)

$\rho$  = 0.284  $\frac{\text{lbs}}{\text{in}^3}$  as the general density of steel.

The categories are:

L-F = Long flat  
 L-C = Long chunky  
 F = Flat  
 F-C = Flat chunky  
 C = Chunky  
 L = Long

The calculated D values can fit appropriate groups for D (Inches):

60-Grain					
Long Flat	Flat	Flat Chunky	Long Chunky	Chunky	Long
<0.450	0.450	0.550	0.650	0.750	>1.500
	<0.550	<0.650	<0.750	<1.500	
240-Grain					
Long Flat	Flat	Flat Chunky	Long Chunky	Chunky	Long
<0.800	0.800	0.850	1.100	1.250	>1.500
	<0.850	<1.100	<1.250	<1.500	

Tables I and II and Figures 3 and 4 show the classification of the fragments. Figures 5 and 6 illustrate the majority of the fragments fired. After firing, many fragments were lost from impacting the sabot catcher, the printed circuit paper holders, or the Nu-Wood holders.

Figures 3 and 4 have regression plots of a penetration equation obtained by firing steel cylinders into wallboard trade named Nu-Wood and Flintkote. These cylinders had characteristic velocities from 305 ft/sec to 12,788 ft/sec, masses from 0.25 grain to 241.50 grains, and 0° to 70° obliquity from the projectile path to the perpendicular to the Nu-Wood surface. The finalized regression equation used for the plot is:<sup>2</sup>

$$V_s = \frac{112621(X)^{0.8091} (KM^{2/3})^{0.9078}}{M^{0.9388}}$$

$V_s$  = Striking velocity of steel cylindrical fragments (ft/sec).

$X$  = Depth of penetration measured perpendicular to the Nu-Wood surface (in.)

$K$  = 0.0088

$M$  = Mass of fragment (grains)

<sup>2</sup> This will be termed the Thor regression equation. The Thor regression plot for cylinders does not fit closely to the distribution of 60-grain and 240-grain bomb fragment data points. This can be attributed to the shape difference between pre-formed cylinders and actual bomb fragments. Also, the Thor regression equation has too large a range in its variables of mass, velocity, and obliquity.

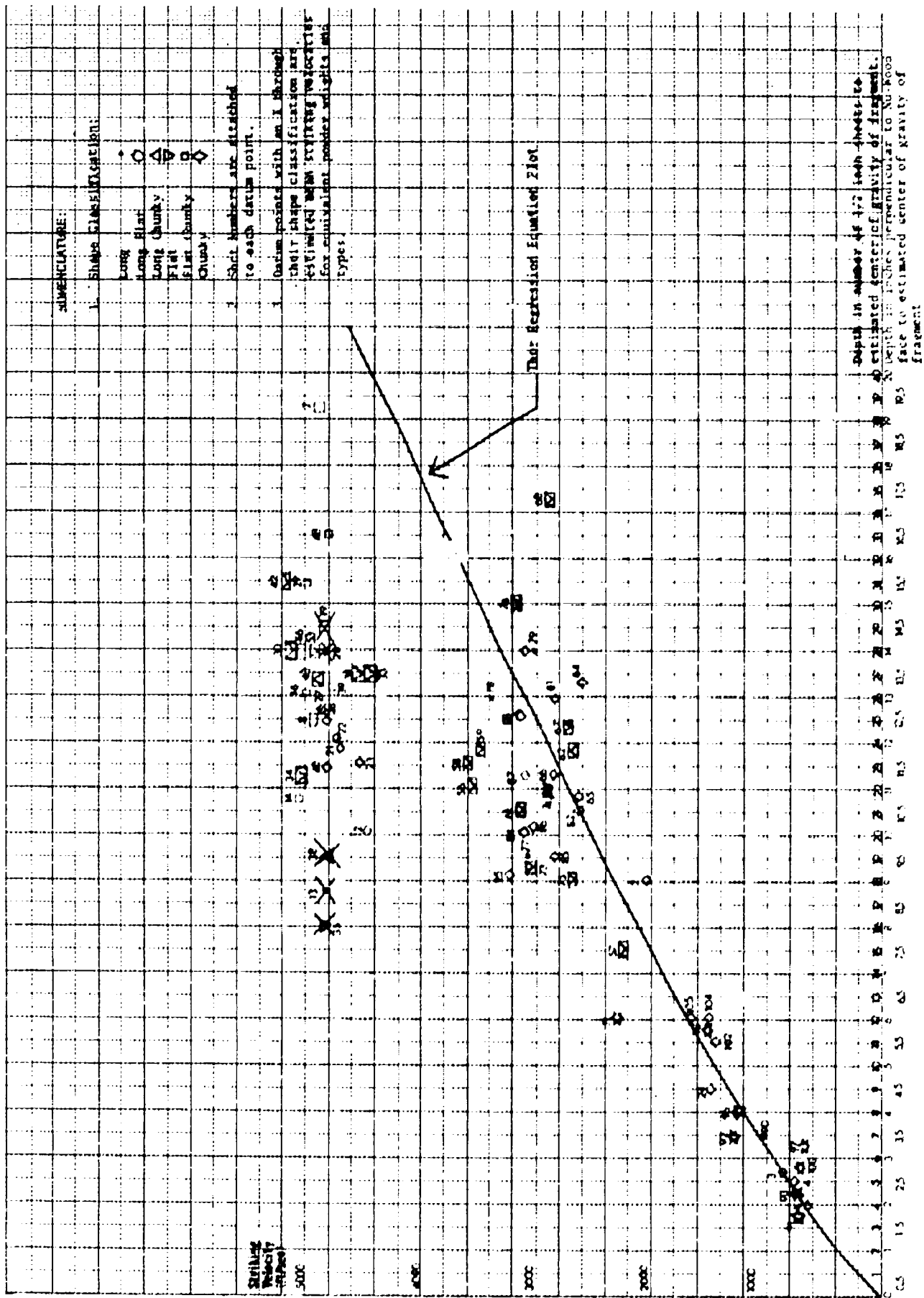


Figure 3. Striking Velocity Versus Penetration into Nu-Wood for 60-Grain Bomb Fragments

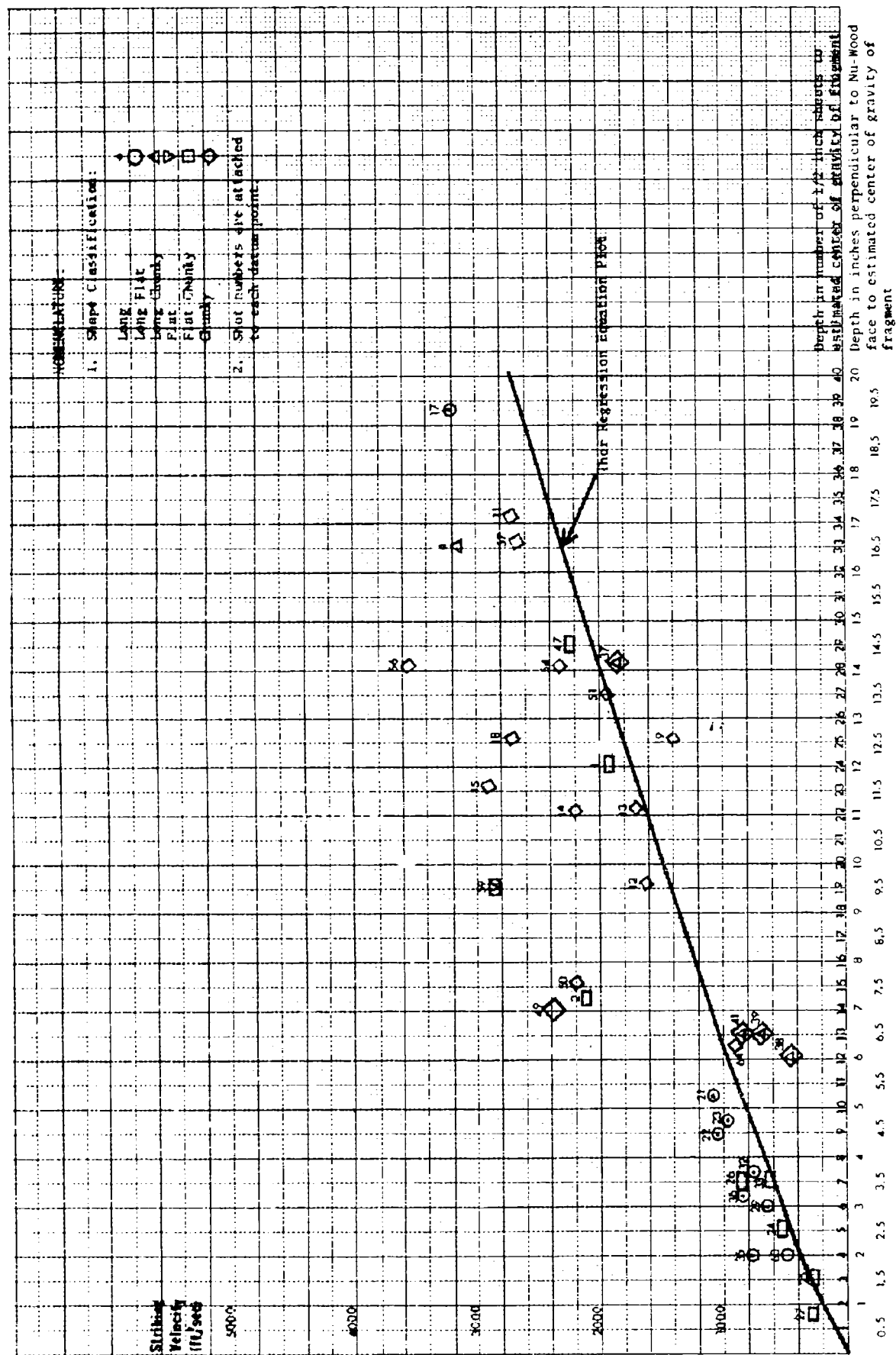


Figure 4. Striking Velocity Versus Penetration into Nu-Wood for 240-Grain Bomb Fragments

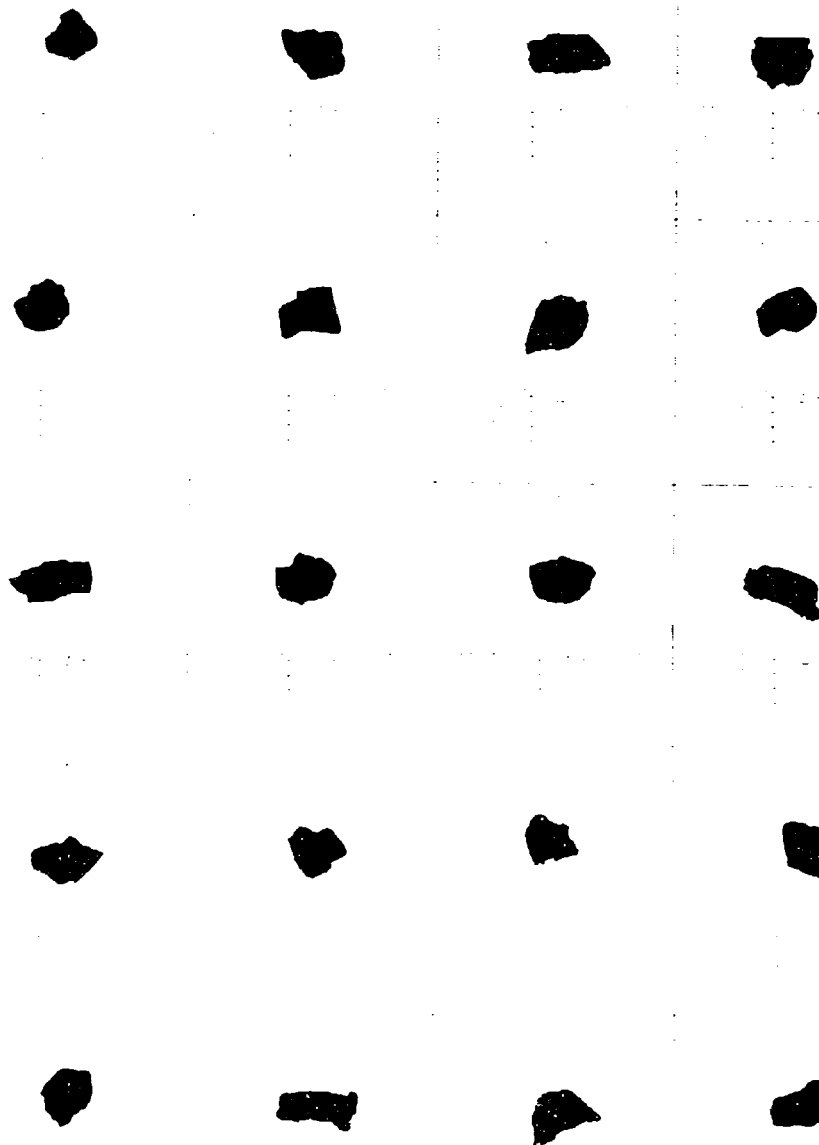


Figure 5. Illustration of the Majority of 60-Grain Bomb Fragments Before Firing

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Figure 5. (Continued)



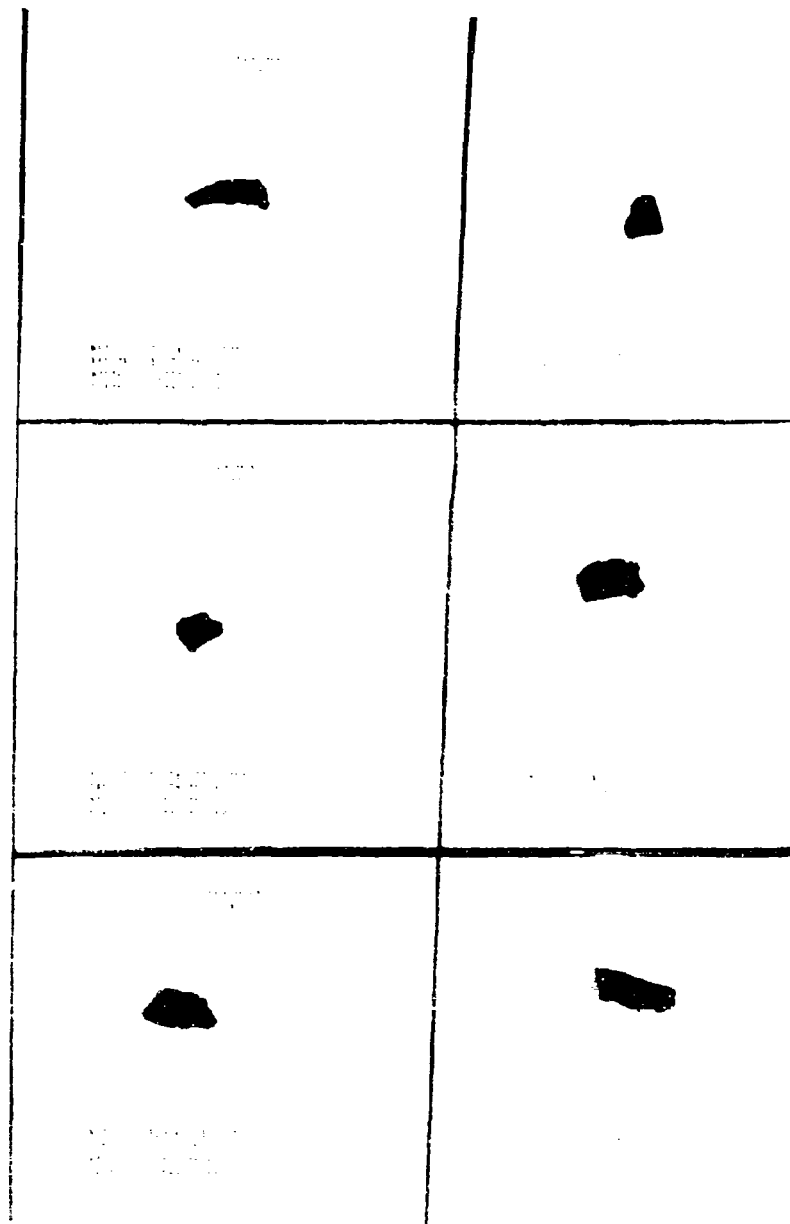


Figure 5. (Concluded)  
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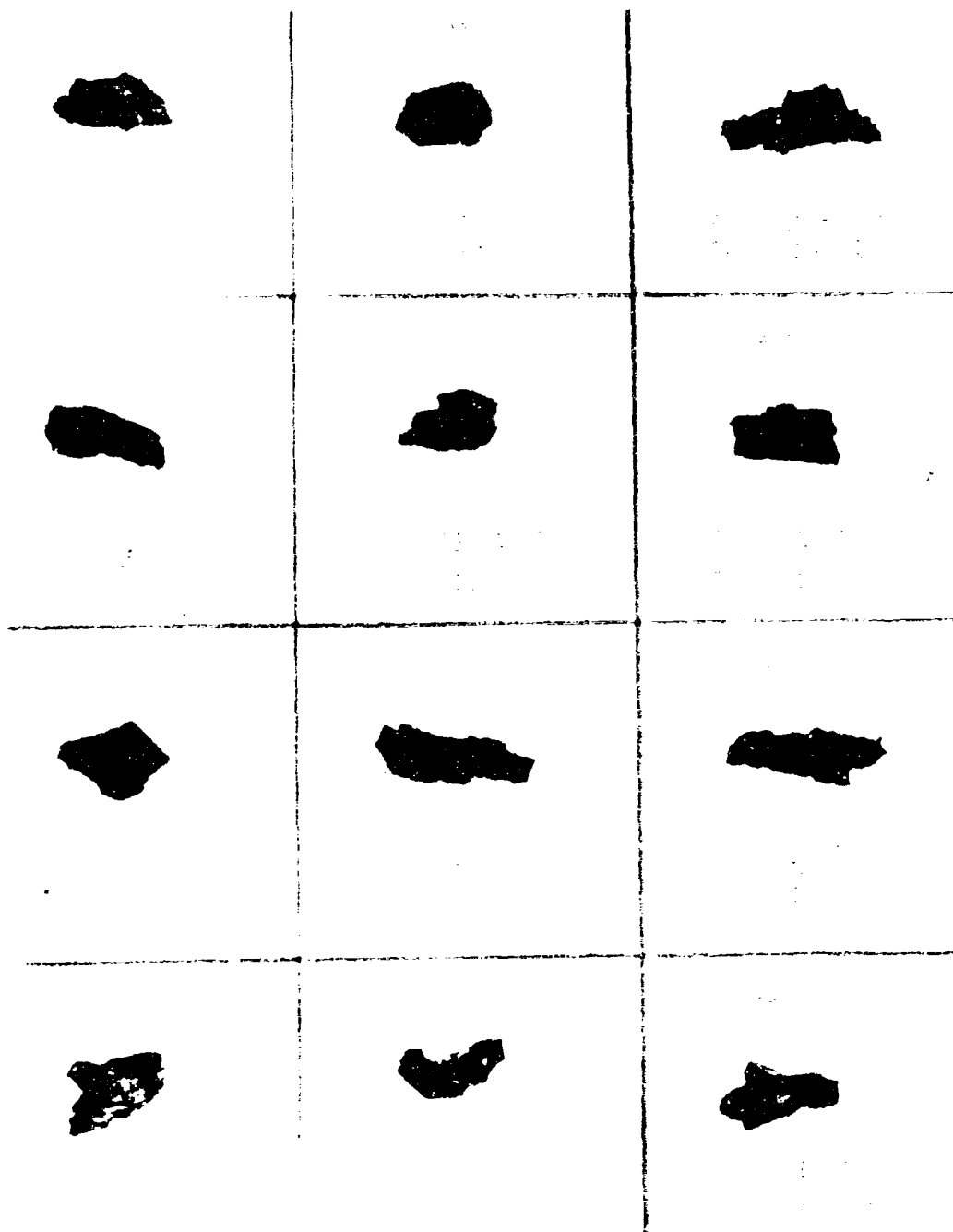


Figure C. Illustration of the Majority of 240-Grain Bomb Fragments Before  
Firing  
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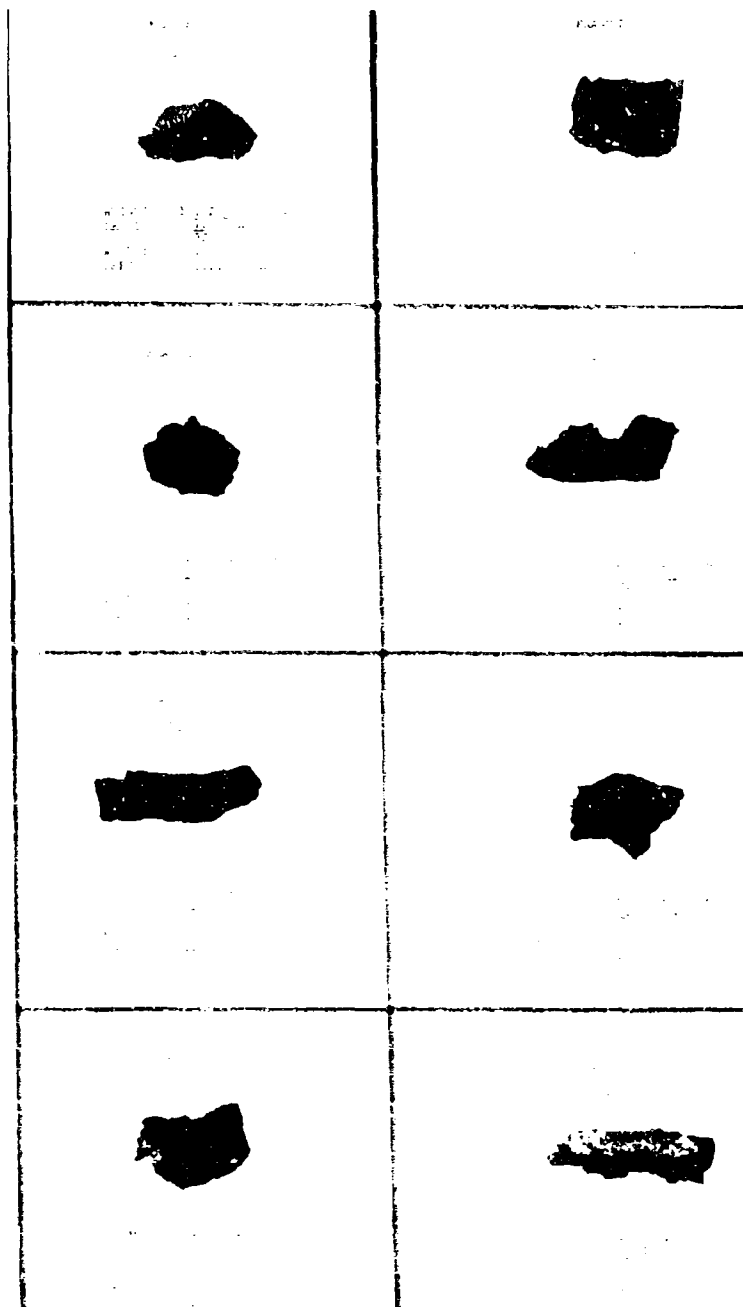


Figure 6 (Concluded)

TABLE 1. 60-GRAIN BOMB FRAGMENT SHAPE CLASSIFICATION, POWDER CHARGE, MEASURED VELOCITY, STRIKING VELOCITY, AND PENETRATION INTO NU-WOOD DATA.

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS), TYPE	MEASURED VELOCITY (FT./SEC.)	STRIKING VELOCITY (10,9514 x MEASURED VELOCITY) (FT./SEC.)	PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
1	1	Chunky	205-1NR4895	679	646	2.00	Good Shot
2	1	Chunky	225-1NR4895	2147	2043	9.00	Good Shot
3	1	Chunky	205-1NR4895	891	848	2.25	Good Shot
4	1	Chunky	210-1NR 855	814	774	2.50	Good Shot
5	1	Chunky	200-8085	371	353	N/A	Fragment made impact hole, then bounced out to be found on floor 6 ft. from Nu-Wood. No recovery. Fragment went under table holding Nu-Wood.
6	1	Chunky	250-8085	450	428	N/A	Good Shot
7	2	Flat Chunk	625-1NR4895	5131	4882	19.25	Strong X-axis deflection in Nu-Wood. Fris (2 1/2", 8 1/2")
8	2	Flat Chunk	625-1NR4895	5171	4920	12.50	Surface co-ordinate to (2 1/8", 9") where found. No recovery. Fragment struck sabot catcher. Fragment struck
9	2	Flat Chunk	625-1NR4895	2760	(4824)	N/A	No recovery. Fragment struck sabot catcher.
10	3	Long Chunk	625-1NR4895	2856	(4824)	N/A	Fragment broke up in flight into four small pieces.
11	4	Flat Chunk	625-1NR4895	3079	(4824)	N/A	Fragment broke up in Nu-Wood. A 50 gram piece appeared to break off in 10th sheet and then emerged to be found in 14th sheet.
12	5	Chunky	625-1NR4895	4697	4469	10.00	A 50 gram weight loss. Cannot locate piece. Still consider as datum point.
13	6	Flat Chunk	631,5-1NR4895	3167	(4824)	9.75	Good Shot
14	6	Flat Chunk	631,5-1NR4895	5299	5041	10.75	No recovery. Fragment struck sabot catcher.
15	6	Flat Chunk	631,5-1NR4895	3212	(4824)	N/A	A 12 gram weight loss. Could not locate piece. Can be considered as a datum point.
16	11	Flat Chunk	631,5-1NR4895	5244	4989	13.12	No recovery.
17	11	Flat Chunk	631,5-1NR4895	3876	(4824)	N/A	No recovery. Appeared fragment broke up in flight. Sabot velocity.
18	16	Flat Chunk	631,5-1NR4895	3042	(4824)	N/A	
19	17	Flat Chunk	631,5-1NR4895	3667	(4824)	14.50	

20	17	Flat Chunk	634.5-1984895	N/A	N/A	No recovery. Fragment hit sabot catcher.
21	8	Chunky	634.5-1984895	4928	11.88	Good shot.
22	8	Chunky	634.5-1984895	4708	14.00	Good shot.
23	8	Chunky	634.5-1984895	4509	11.62	Good shot.
24	8	Chunky	634.5-1984895	1475	4.50	Good shot.
25	8	Chunky	634.5-1984895	3392	9.12	Good shot.
26	8	Chunky	634.5-1984895	5961	12.50	Good shot.
27	8	Chunky	634.5-1984895	1692	12.50	Shot velocity.
28	8	Chunky	634.5-1984895	5315	14.00	Break up occurring. Sheet 7 got .30 gram piece, sheet 26 got .45 gram piece and main fragment weighing 3.53 grams.
29	10	Flat Chunk	634.5-1984895	4982	15.50	Good shot.
30	10	Flat, Flat Chunk	634.5-1984895	5113	14.00	Good shot.
31	10	Flat, Flat Chunk	634.5-1984895	4557	13.50	A .05 gram break-off. Could not locate piece. Still considered as a datum point.
32	22	Long Chunk	634.5-1984895	4824	N/A	No recovery.
33	19	Flat, Flat Chunk	634.5-1984895	4563	13.50	Good shot.
34	19	Flat, Flat Chunk	634.5-1984895	5023	11.25	A .10 gram weight loss. Could not locate piece. Still considered as datum point.
35	7	Flat	634.5-1984895	4824	8.00	A .05 gram weight loss. The .10 gram piece found in 6th sheet. Could not find .05 gram piece.
36	7	Flat	634.5-1984895	4824	N/A	No recovery. Fragment hit Nu-Wood holder.
37	23	Long Chunk	634.5-1984895	4824	N/A	Fragment appeared to break up and strike Nu-Wood holder.
38	18	Long Chunk	634.5-1984895	4824	9.50	Sabot velocity.
39	15	Flat Chunk	634.5-1984895	4765	13.25	Bad shot. A .20 gram weight loss. Piece found in 10th sheet.
40	20	Chunky	634.5-1984895	4824	11.50	Sabot velocity.
41	20	Chunky	634.5-1984895	4824	N/A	No recovery. Fragment went into table holding Nu-Wood.
42	19	Flat, Flat Chunk	634.5-1984895	5156	15.50	A .05 gram weight loss. Still a good datum point.
43	13	Flat Chunk, Long Chunk	634.5-1984895	4824	13.00	A .30 gram weight loss. Could not find piece.
44	18	Long Chunk	634.5-1984895	4824	N/A	No recovery. Fragment hit sabot catcher.
45	9	Long Chunk	634.5-1984895	4824	N/A	No recovery. Fragment hit sabot catcher.
46	16	Flat Chunk	634.5-1984895	5056	14.00	A .60 gram weight loss. Could not find piece.

TABLE I. (CONCLUDED)

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS) & TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (FT/SEC)	NO-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NO-WOOD SURFACE TO LATEST HOLE CENTER OF GRAVITY OF FRAGMENT (INCHES)		COMMENTS
						1/4	3/4	
47	26	Flat, Flat Chunk	6.25-19R4895	4670	4399	16.50		No recovery. Fragment hit sabot catcher.
48	14	Flat Chunk	6.25-19R4895	5075				A 10 gram weight loss.
49	14	Flat Chunk	6.25-19R4895	4674	3685	N/A		Struck a good datum point.
50	12	Long Chunk	6.25-19R4895	5276	(4824)	N/A		Fragment broke up in flight.
51	25	Flat Chunk, Long Chunk	6.25-19R4895	(5070)	(4824)	N/A		No recovery.
52	24	Flat Chunk, Long Chunk	6.25-19R4895	(5070)	(4824)	N/A		No recovery.
53	19	Flat, Flat Chunk	6.25-19R4895	5220	(4824)	14.00		Velocity too high.
54	9	Long Chunk	6.25-19R4895	4915	(4824)	1/4		No recovery. Fragment hit sabot catcher.
55	27	Flat, Flat Chunk	6.25-19R4895	5273	(4824)	N/A		No recovery. Fragment hit sabot catcher.
56	19	Flat, Flat Chunk	400-19R4350	5441	5558	11.00		Good shot.
57	19	Flat, Flat Chunk	370-19R4350	5351	5558	11.50		Good shot.
58	19	Flat, Flat Chunk	470-19R4350	5360	5562	11.50		Good shot.
59	19	Flat, Flat Chunk	450-19R4350	5360	5481	11.75		Good shot.
60	19	Flat, Flat Chunk	410-19R4350	5360	5448	N/A		Fragment hit another hole in No-wood.
61	19	Flat, Flat Chunk	400-19R4350	5294	5151	10.50		Good shot.
62	29	Flat Chunk, Long Chunk	590-19R4350	5815	5675	11.75		Good shot.
63	29	Flat Chunk, Long Chunk	390-19R4350	4981	(2617)	N/A		No recovery. Fragment hit sabot catcher.
64	30	Chunky	390-19R4350	(2715)	2613	15.25		Good shot.
65	30	Chunky	400-19R4350	5000	2607	10.75		Good shot.
66	30	Chunky	400-19R4350	5000	2835	11.25		Good shot.
67	36	Flat, Flat Chunk	400-19R4350	5000	2741	12.25		Good shot.
68	36	Flat, Flat Chunk	400-19R4350	5000	2882	17.25		Good shot.
69	40	Long Flat, Long Chunk	400-19R4350	(2967)	(2818)	N/A		No recovery. Fragment hit sabot catcher.
70	31	Long Chunk	400-19R4350	2782	2617	8.00		Good shot. A 1.16 gram weight loss. Could not find piece.
71	39	Flat, Long Chunk	400-19R4350	2406	2289	6.00		Good shot. Different car.
72	39	Flat, Long Chunk	400-19R4350	2462	2342	N/A		No powder used.
73	36	Flat, Flat Chunk	420-19R4350	5000	5000	9.25		No recovery. Fragment hit No-wood holder.
74	36	Flat, Flat Chunk	420-19R4350	5000	5013	11.00		Good shot.

75	36	Flat, Flat Chunk	425-198750	2807	2671	9.00	Good shot.
76	36	Flat, Flat Chunk	425-198750	3347	3170	15.00	Good shot.
77	34	Long	425-198750	2282	(3033)	9.50	Subot velocity.
78	34	Long	420-198750	3536	3364	15.00	Good shot.
79	34	Long	420-198750	3158	3004	14.00	Good shot.
80	-	Long	420-198750	N/A	(2987)	N/A	No recovery.
81	34	Chunky	400-198750	3008	2862	13.00	Good shot.
82	33	Chunky	400-198750	2782	2647	10.50	Good shot.
83	38	Chunky	400-198750	3185	3034	14.00	Good shot.
84	38	Chunky	400-198750	3270	3111	10.00	Good shot.
85	38	Chunky	400-198750	2989	2843	9.50	Good shot.
86	37	Chunky	400-198750	3290	3130	10.00	A .05 gram weight loss. Still can be considered a datum point.
87	38	Chunky	400-198750	3278	3110	11.25	Good shot.
88	38	Chunky	400-198750	3093	3133	12.50	Good shot.
89	36	Flat, Flat Chunk	425-198750	302	78	N/A	No recovery. Fragment hit Ag-wood holder.
90	34	Long	425-198750	3179	36	12.50	Good shot.
91	39	Flat, Long Chunk	425-198750	746	710	2.00	Good shot.
92	39	Flat, Long Chunk	425-198750	1369	302	3.50	Good shot.
93	39	Flat, Long Chunk	425-198750	746	757	2.25	Good shot.
94	39	Flat, Long Chunk	425-198750	1332	1767	N/A	Bad shot. Fragment dropped out of 3rd sheet.
95	39	Flat, Long Chunk	425-198750	703	669	N/A	Went through (or pushed a hole in) 5 sheets and bounced out to be found 15 ft. in front of target.
96	39	Flat, Long Chunk	425-198750	1312	1218	4.00	Good shot.
97	39	Flat, Long Chunk	425-198750	710	677	5.25	Good shot.
98	39	Flat, Long Chunk	425-198750	1610	1537	5.25	Good shot.
99	39	Flat, Long Chunk	425-198750	746	710	N/A	Forgot to get depth of penetration.
100	39	Flat, Long Chunk	425-198750	730	703	2.50	Good shot.
101	39	Flat, Long Chunk	425-198750	1095	1001	N/A	Bad shot.
102	38	Chunky	425-198750	1245	1354	5.50	Good shot.
103	38	Chunky	425-198750	497	468	N/A	Bad shot. Bounced out and hit floor.
104	37	Chunky	425-198750	617	1351	6.00	Good shot.
105	35 (37)	Chunky	425-198750	1744	1650	6.00	Good shot except for possible mistaken identity of fragment.

Nonconformance: 1. N/A. Not applicable.  
2. Velocities in parentheses are the mean velocities for equivalent powder weights and types. These are quite reliable and are plotted in Figure 3.

TABLE II. 240-GRAIN BOMB FRAGMENT SHAPE CLASSIFICATION, POWDER CHARGE  
MEASURED VELOCITY, STRIKING VELOCITY, AND PENETRATION INTO NU-WOOD DATA.

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAIN)	DATE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (9.8514 x MEASURED VELOCITY) (FT/SEC)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
1	19	Flat Chunk	300-19R4350		2641	1975	12.00	Good shot.
2	19	Flat Chunk	600-19R4350		2255	2170	7.25	Good shot.
3	19	Flat Chunk	850-19R4350		1964	1897	N/A	Sabot velocity. Fragment struck Nu-Wood holder frame. Fragment broke up into two halves at final fragment location.
4	17	Long Chunk	850-19R4350		3313	3230	16.50	No velocity recorded. Bad shot.
5	15	Long Chunk	800-19R4350		N/A	N/A	9.00	Bad shot. Fragment hit sabot catcher. Sabot velocity.
6	18	Long Chunk	800-19R4350		2264	2187	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
7	5	Flat, Flat Chunk	800-19R4350		2494	2409	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
8	8	Long Chunk	800-19R4350		2355	2275	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
9	6	Long Chunk	800-19R4350		N/A	N/A	N/A	Fragment hit catcher. Bad shot. No time recorded.
10	10	Long Flat*	800-19R4350		471	453	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
11	2	Chunk	800-19R4350		2855	2758	17.00	Good shot.
12	2	Chunk	825-19R4350		1749	1690	9.50	Good shot.
13	2	Chunk	825-19R4350		1834	1772	11.00	Good shot.
14	2	Chunk	700-19R4895		2339	2260	11.00	Good shot.
15	2	Chunk	800-19R4895		3012	2939	11.50	Good shot.
16	14	Long, Long Flat	800-19R4895		2992	2891	N/A	Bad shot. Fragment hit sabot catcher.
17	13	Long, Long Flat	800-19R4895		3320	3256	19.25	Good shot.
18	7	Chunk	800-19R4895		2856	2759	12.50	Good shot.
19	7	Flat Chunk	300-19R4895		1218	1160	12.50	Good shot.
20	16	Flat Chunk	250-19R4895		489	472	N/A	Bad shot. Fragment hit sabot catcher.
21	13	Long, Long Flat	250-19R4895		1181	1141	5.25	Good shot.
22	12	Long, Long Flat	240-19R4895		1141	1102	4.50	Good shot.
23	12	Long, Long Flat	230-19R4895		1054	1018	4.75	Good shot.
24	11	Flat Chunk	225-19R4895		599	579	2.50	Good shot.
25	11	Flat Chunk	228-19R4895		545	535	1.50	Good shot.
26	11	Flat Chunk	230-19R4895		917	886	3.50	Good shot.
27	16	Flat Chunk	250-19R4895		515	501	.75	Good shot.



28	16	Flat Chunk	250-1984505	517	306	N/A	Bad shot. Fragment hit catcher.
29	20	Long, Long Flat	210-1981805	714	690	3.09	Good shot.
30	20	Long, Long Flat	210-1981805	1050	1074	2.00	Bad shot. No bond not packed.
31	20	Long, Long Flat	245-1981805	410	431	N/A	Bad shot. Hit sabot catcher.
32	15	Long, Long Flat	245-1981805	1917	1912	3.25	Good shot.
33	15	Flat Chunk	245-1981805	721	697	3.50	Good shot. Hit sabot catcher.
34	15	Long, Long Flat	500-1981805	507	355	N/A	Good shot.
35	15	Long, Long Flat	500-1981805	801	852	2.00	Good shot.
36	15	Long, Long Flat	500-1981805	970	880	3.25	Good shot.
37	15	Chunks, Long Chunk	600-1981805	1910	1871	11.00	Depth and velocity seem quite unrelated. This is probably due to fragment's shape character.
38	4	Chunks, Long Chunk	600-1981805	517	301	6.00	Good shot. Again, fragment's shape is causing great depth.
39	4	Chunks, Long Chunk	600-1981805	780	751	6.50	Bad shot. No velocity and fragment hit sabot catcher.
40	4	Chunks, Long Chunk	800-1981805	N/A	N/A	N/A	Good shot. Fragment hit sabot catcher. Sabot velocity recorded.
41	7	Chunks	900-1981805	667	834	6.50	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
42	2	Chunks	900-1981805	1907	1827	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
43	9	Flat Chunk	800-1981805	2317	2254	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
44	1	Long Chunk	800-1981805	2577	2586	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
45	13	Long, Long Flat	800-1981805	2064	2025	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
46	15	Long, Long Flat	800-1981805	N/A	N/A	N/A	Bad shot. Fragment hit printed circuit paper holder.
47	11	Flat Chunk	800-1981805	2380	2209	14.50	Bad shot. No velocity and fragment hit sabot catcher.
48	11	Flat Chunk	800-1981805	2407	2385	N/A	Good shot.
49	22	Chunks	800-1981805	2490	2412	7.00	Bad shot. Fragment hit sabot catcher. Sabot velocity.
50	21	Chunks	800-1981805	2552	2272	7.50	Good shot.
51	27	Chunks	1000-1981805	2067	1907	15.50	Good shot.
52	26	Chunks	1000-1981805	2427	2331	N/A	Bad shot. Fragment hit catcher.
53	27	Chunks	1000-1981805	2910	2811	N/A	Bad shot. Fragment hit catcher.
54	22	Chunks	1000-1981805	2443	2360	14.00	Good shot.
55	24	Chunks	1000-1981805	N/A	N/A	N/A	Bad shot. No velocity and fragment hit sabot catcher.
56	22	Chunks	1000-1981805	3227	3001	14.00	Good shot.

TABLE II. (CONCLUDE)

TEST NO.	PENETRATOR NO.	SHAPE CLASSIFICATION	PINDER WEIGHT (GRAINS), TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (FT/SEC)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
				28.36	27.30	16.50	
58	22	Chunky	1000-19R4350	2966	2805	N/A	Good shot.
59	23	Flat, Flat Chunk	1000-19R4350	3008	2906	9.50	Bad shot. Fragment hit catcher. Sabot velocity.
60	5	Long Flat	250-19R4350	564	545	2.00	Good shot.
61	3	Long Flat	300-19R4350	1218	1122	8.25	Good shot. A 1-grain weight loss. Did not locate piece.
62	21	Chunky	280-19R4350	995	961	N/A	Bad shot. Hit too close to another hole.
63	21	Chunky	280-19R4350	881	851	N/A	Bad shot. Fragment hit sabot catcher.
64	28	Chunky	280-19R4350	922	896	6.50	Good shot.

Notation: 1. N/A: Not applicable.

2. There are no estimated velocities from equivalent powder weights and types for these firings.

## SECTION IV

### SECONDARY OBJECTIVES

When a difference factor of two or greater exists in impact presented area between two 60-grain fragments at the same velocity, then the presented area seems to be an independent variable in penetration. Table III helps to support this conclusion.

The presented area upon impact of 240-grain fragments does not seem to be a significant variable in depth of penetration. This conclusion results from studying Table IV.

The 60-grain fragment break-offs were generally located along the fragment path. This is contrary to the 15-grain study where the break-offs were at the final mother fragment position. The 240-grain fragments had few breakoffs and not enough study was given about their origin.

For the same velocity and mass the penetration could be related to a function of many variables:

Penetration = F (Fragment shape, fragment surface, fragment tumbling before and after impact, fragment impacting presented area, compression of Nu-Wood, etc.)

An examination of bore sight, fragment entrance, and finalized position in Nu-Wood co-ordinates reveals no appreciable air deflection and Nu-Wood deflection of fragments. Air deflection could be attributed to the sabot aiming the fragment after exit from the Mann barrel. Since the Nu-Wood deflection is slight, no transformations are made on the perpendicular to Nu-Wood surface penetration data. All the penetration data in Figures 3 and 4 need not be corrected for the slight angular deflections in Nu-Wood.

Some other interesting facts found from testing are:

- a. The recovered fragments had Nu-Wood clinging to them.
- b. As the fragment goes deeper into the Nu-Wood it tends to make a large and less clean or sharp hole. This could be attributed to Nu-Wood building up on the fragment as it penetrates.
- c. The Lexan sabot will be dented on its base from the fragment's initial momentum impulse.
- d. For better air flight stability a sabot fitting a fragment is better than a sabot with a hole too large.

TABLE III. PRESENTED AREAS OF IMPACTING 60-GRAIN BOMB FRAGMENTS

SHOT FRAGMENT		SHAPE CLASS	X (DEPTH OF PENETRATION PERPENDICULAR TO NU- WOOD SURFACE TO ES- TIMATED CENTER OF GRAVITY OF FRAGMENT)	A (PRESENTED AREA OF FRAGMENT)	V (STRIKING VELOCITY)
NO.	NO.		(INCHES)	(INCHES <sup>2</sup> )	(FT./SEC)
91	39	Flat, Long Chunky	2.00	.2050	710
93	39	Flat, Long Chunky	2.25	.1175	757
4	1	Chunky	2.50	.1450	774
3	1	Chunky	2.75	.1275	848
1	1	Chunky	2.00	.1250	646
97	39	Flat, Long Chunky	3.25	.0225	675
92	39	Flat, Long Chunky	3.50	.1675	1302
96	39	Flat, Long Chunky	4.00	.0475	1248
24	8	Chunky	4.50	.1700	1475
102	38	Chunky	5.50	.1013	1451
105	35	Chunky	6.00	.1825	1659
104	37	Chunky	6.00	.1250	1534
71	39	Flat, Long Chunky	6.00	.2075	2289
57	19	Flat, Flat Chunky	7.50	.0763	2237
75	36	Flat, Flat Chunky	9.00	.2388	2671
82	33	Chunky	10.50	.1650	2647
65	30	Chunky	10.75	.1150	2657
62	29	Flat Chunky, Long Chunky	11.75	.1175	2678
64	30	Chunky	13.25	.0800	2613
85	38	Chunky	9.50	.1413	2844
66	30	Chunky	11.25	.1390	2845
51	33	Chunky	13.00	.0863	2862
68	36	Flat, Flat Chunky	17.25	.0450	2882
73	36	Flat, Flat Chunky	9.25	.0975	3039
83	38	Chunky	14.00	.1300	3034
79	34	Long	14.00	.0713	3004
86	37	Chunky	10.00	.1475	3130
84	38	Chunky	10.00	.1600	3111
61	19	Flat, Flat Chunky	10.50	.0925	3134
87	38	Chunky	11.25	.1150	3119
88	38	Chunky	12.50	.1463	3133
76	36	Flat, Flat Chunky	15.00	.1188	3179
56	19	Flat, Flat Chunky	11.00	.1250	3559
58	19	Flat, Flat Chunky	11.50	.1100	3582
23	8	Chunky	11.62	.2019	4509
31	19	Flat, Flat Chunky	13.50	.1450	4537
33	19	Flat, Flat Chunky	13.50	.1838	4503
21	8	Chunky	11.86	.1925	4688
22	8	Chunky	12.00	.2200	4708
26	8	Chunky	12.50	.0888	4815
48	14	Flat Chunky	16.50	.1238	4790
8	2	Flat Chunky	12.50	.2238	4920
16	11	Flat Chunky	13.12	.1125	4989
29	10	Flat Chunky	14.50	.0800	4982
14	6	Flat Chunky	10.75	.1494	5041
34	19	Flat, Flat Chunky	11.25	.2288	5023

TABLE IV. PRESENTED AREAS OF IMPACTING 240-GRAIN BOMB FRAGMENTS

SHOT NO.		X (DEPTH OF PENETRATION PERPENDICULAR TO NU- WOOD SURFACE TO ES- TIMATED CENTER OF GRAVITY OF FRAGMENT)		A (PRESENTED AREA OF FRAGMENT) (INCHES <sup>2</sup> )		V (STRIKING VELOCITY) (FT/SEC)	
FRAGMENT NO.		SHAPE CLASS		(INCHES)			
1	19	Flat	Chunky	12.00	.1650		1975
51	27	Chunky		13.50	.3875		1997
2	19	Flat	Chunky	7.25	.6850		2179
14	2	Chunky		11.00	.1400		2260
60	3	Long Flat		2.00	.1125		545
38	4	Chunky, Long	Chunky	6.00	.1913		501
26	11	Flat	Chunky	3.50	.2638		886
41	7	Chunky		6.50	.4013		838
64	28	Chunky		6.50	.3050		896
22	12	Long, Long Flat		4.50	.5000		1102
21	13	Long, Long Flat		5.25	.0900		1141
49	21	Chunky		7.00	.0650		2414
54	22	Chunky		14.00	.2888		2360
59	23	Flat, Flat	Chunky	9.50	.0663		2906
15	2	Chunky		11.50	.3463		2939
12	2	Chunky		9.50	.3275		1690
13	2	Chunky		11.00	.5250		1772
37	4	Chunky, Long	Chunky	14.00	.2888		1874
14	2	Chunky		11.00	.1400		2260
47	11	Flat	Chunky	14.50	.1300		2299
18	7	Chunky		12.50	.4525		2759
11	2	Chunky		17.00	.4150		2758

## SECTION V

### CONCLUSIONS

The fundamental conclusions are:

- a. The existing Thor equation predictions for cylinders do not fit actual 60-grain and 240-grain bomb fragment data.
- b. Depth of penetration into Nu-Wood is not a reliable method to predict velocities for 60-grain and 240-grain bomb fragments.
- c. The depth of penetration is not a primary function of impact presented area for 60-grain and 240-grain bomb fragments. The 60-grain fragments seem more sensitive to impact presented area than the 240-grain fragments.

#### REFERENCES

1. Section II of USAF TH 61A1-3-7 titled, "JMEM/AS Joint Service Test Procedures for High Explosive Bomb and Bomblets."
2. Malick, Donald, The Calibration of Wallboard for the Determination of Partical Speed, Ballistic Analysis Laboratory, TR-61, May 1966, Page 16.

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14 ABSTRACT: The primary objective of this program was to define a function between the striking velocity for 60-grain and 240-grain random shaped bomb fragments and their depth into the wallboard trade named Nu-Wood. The 60-grain fragments were fired from a 20mm Mann barrel and the 240-grain fragments from a 30mm Mann barrel into bundled Nu-Wood. The 60-grain fragments were lightly filed to fit into a $3.77 \leq w < 4.01$ gram weight range and the 240-grain fragments into a $15.08 \leq w < 16.07$ gram weight range. The striking velocities for the 60-grain fragments were in the 600 ft/sec to 5000 ft/sec range and the 240-grain fragments in the 300 ft/sec to 3500 ft/sec range. The graph of fragment striking velocity as a function of depth into Nu-Wood showed a wide range of depths for approximately 2000 ft/sec and above striking velocities. A lower dispersion in penetration depths exists for velocities up to 2000 ft/sec. A least squares curve would not be valuable since the penetration spread is too wide at given velocities. Fragment penetration into Nu-Wood from firing cylinders does not give a realistic picture of 60-grain and 240-grain actual bomb fragmentation spread. The depth of penetration is not a primary function of the initial presented areas of impacting 240-grain fragments for 500 ft/sec to 3000 ft/sec velocities. When a factor of two or more exists between impacting presented areas for 60-grain bomb fragments, then the presented area seems to influence penetration.			

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